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13. ABSTRACT (Maximum 200 words)

In this work we have modified a semi-empirical correlation for evaluating heat transfer coefficients for a variety of liquids possessing different physico-thermal properties. The liquids under investigation were hydrocarbons and distilled water. Data were chosen for a wide range of heating surfaces, heat flux, and pressures. The correlation for heat transfer coefficient is based on two main factors contributing for heat removal from the surface. The correlation is:

$$h = \frac{2}{\sqrt{\pi}} \sqrt{k_l c_l \rho_l} \sqrt{f} + \frac{1}{6} \rho_v \lambda f D_b \frac{1}{\Delta T_w}$$

The first factor includes removal of heat by transient heat conduction to, and subsequent replacement of, superheated layer around boiling sites. The second factor takes into account the latent heat transport during growth of vapor bubbles. The equations for bubble emission frequency, f were developed analytically. Laplace Equation was used for the bubble departure diameters. The correlation predicts boiling heat transfer data well for hydrocarbons and distilled water.
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Semi-Analytical Determination of Heat Transfer Coefficients in Nucleate Pool Boiling of Pure Liquids*

Angela Lee, Tameka Harrison
&
Parashu Sharma

Grambling State University

February 2, 1996

INTRODUCTION

This work attempts to modify the correlation earlier developed by Blöchl [1] for nucleate pool boiling heat transfer. We have developed the expressions for bubble emission frequency and tested this correlation at atmospheric and subatmospheric pressures for pure liquids. An analytical correlation for nucleate pool boiling should include the underlying mechanism of boiling heat transfer. Proper consideration should be given to the various heat transport factors responsible for removing the heat from the heat transfer surface in a boiling heat transfer process.

ANALYSIS:

The correlation is based on two main factors which contribute the removal of heat from the heat transfer surface.

The first factor suggested by Mikic and Rohsenow [2] postulates that the main mechanism of heat transfer in nucleate boiling is transient heat conduction to, and subsequent replacement of, superheated layer around boiling sites.

The second factor comes during the growth of vapor bubbles and their subsequent departure. Rallis and Jawurek [3] and Paul and Abdel-Khalik [4] have suggested that the latent heat transport plays a considerable role for the removal of heat from the heat transfer surface.

CORRELATION

$$(h)\text{pred} = \frac{2}{\sqrt{\pi}} \sqrt{kl\ cl\ \rho l}\ \sqrt{f}$$

$$+ \frac{1}{6}\ \rho v\ \lambda\ f\ Db\ \frac{1}{\Delta Tw}$$

The first factor represents the part of the heat removed due to conduction heat transfer from the surface to the adjacent liquid layer. When the sufficient degree of superheat is reached the bubbles start nucleating on the surface. It is believed that a larger portion of heat is removed because of this conduction process in the vicinity of the wall.

The removal of heat by this conduction process can be taken into account by the product of thermal accommodation factor (given by the product of thermal conductivity, specific heat, and density of boiling liquid and taking the square root of this product) and square root of bubble emission frequency.

The correlations for bubble emission frequency were earlier developed and presented in Louisiana Academy of Science Meeting by Terrell Ford. The same correlations are used in this work to calculate the value of heat transfer coefficient.

The equations for the bubble emission frequency for different ranges of Jakob numbers are:

$$f = \cfrac{1}{\cfrac{[133.3/P]^2 [\sigma/(\rho_1 - \rho_v)g}{\pi \; \alpha_1 \; Ja^2} + \cfrac{0.867}{\alpha_1}[\cfrac{k_1 \Delta T_w}{q_w}]^2}$$

for $Ja \leq 100$

$$f = \cfrac{1}{\cfrac{[133.3/P]^2 [\sigma/(\rho_1 - \rho_v)g}{25\alpha_1 Ja^{3/2}} + \cfrac{0.867}{\alpha_1}[\cfrac{k_1 \Delta T_w}{q_w}]^2}$$

for $Ja > 100$

where $\quad Ja = \cfrac{C_1 \; \rho_1 \; \Delta T_w}{\rho_v \; \lambda}$

The second factor represents the part of the heat removed by latent heat transport during the formation of the vapor bubbles until their departure. The quantity $\frac{1}{6} \rho_v \lambda f D_b \frac{1}{\Delta T_w}$ reflects this portion of heat transfer coefficient. The D_b is the diameter of the bubble at the time of departure and ΔT_w is the degree of wall superheat.

RESULTS

Heat transfer coefficients were calculated using this correlation for the data of Sharma. The predicted values of heat transfer coefficient were compared with the experimental values. The correlation predicted the data remarkably well within 10 per cent.

The study also reveals the effect of heat flux and pressure on bubble emission frequency and bubble departure diameter. Bubble frequency is the strong function of heat flux. It increases with increase in heat flux. Bubble frequency also is a function of pressure. An increase in pressure shows increase in frequency in bubble emission. The calculations also reflect the effect of pressure on bubble departure diameter. The bubble departure diameters decrease with increase in pressure.

CONCLUSIONS

Following conclusions can be drawn from this investigation:

1. Heat transfer rates in nucleate pool boiling are contributed by both conduction and latent heat transport. The conduction heat transfer plays more significant role.

2. The data correlates very well with the experimental data.

3. The study also reveals the effect of heat flux and pressure on bubble frequency and departure diameter. The frequency is a strong function of heat flux and also increases with increase in pressure while the bubble departure diameter decreases with increase in pressure.

REFERENCES

1. Blöchl, R. " Zum Einfluß der Oberflächenstruktur unterschiedlich bearbeiteter Heizflächen auf die Wärmeübertragung beim Blasensieden", Diss., Universität Karlsruhe (TH), 1986.

2. Mikic, B.B. and Rohsenow, W.M., " A new correlation of pool-boiling data including the effect of heating surface characteristics", Trans. ASME, Ser. C, J. Heat Transfer, pp 245-250 (1969).

3. Rallis, C.J. and Jawurek, H.H., " Latent heat transport in saturated nucleate boiling", Int. J. Heat Mass Transfer, Vol.7, pp1051-1068 (1964).

4. Paul, D. D. and Abdel-Khalik S. I., " A statistical analysis of saturated nucleate boiling along a heated wire", Int. J. Heat Mass Transfer, Vol. 25, No. 8, pp.509-518 (1982)

5. Sharma, P.R., Heat Transfer Studies in Pool Boiling of Liquids", Ph.D. Thesis, University of Roorkee, Roorkee (1977)

Exptl Data for Water at 98.44 kPa vs Data by Present Analysis
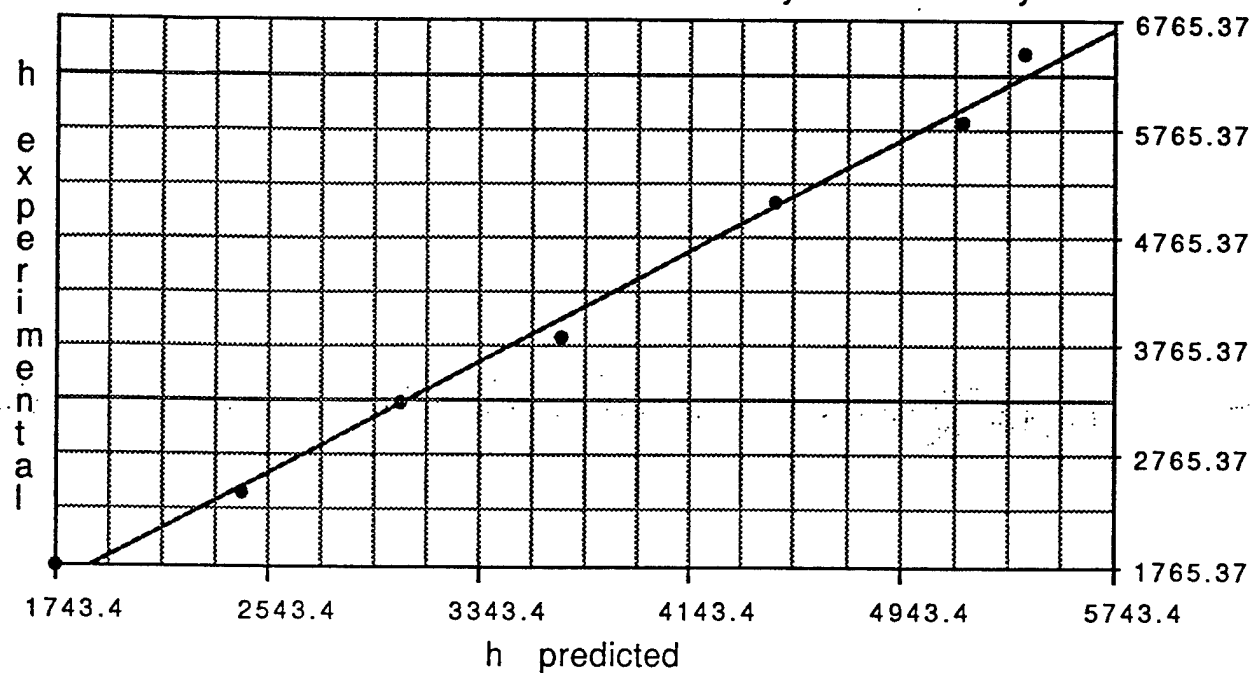
Report Created: 03-22-1995   11:45:00 AM

Linear Best Fit Curve
Pts Plotted = 7   Offscale Pts = 0

Regression Equation:
$Y = 1.26898 X + (-602.501)$

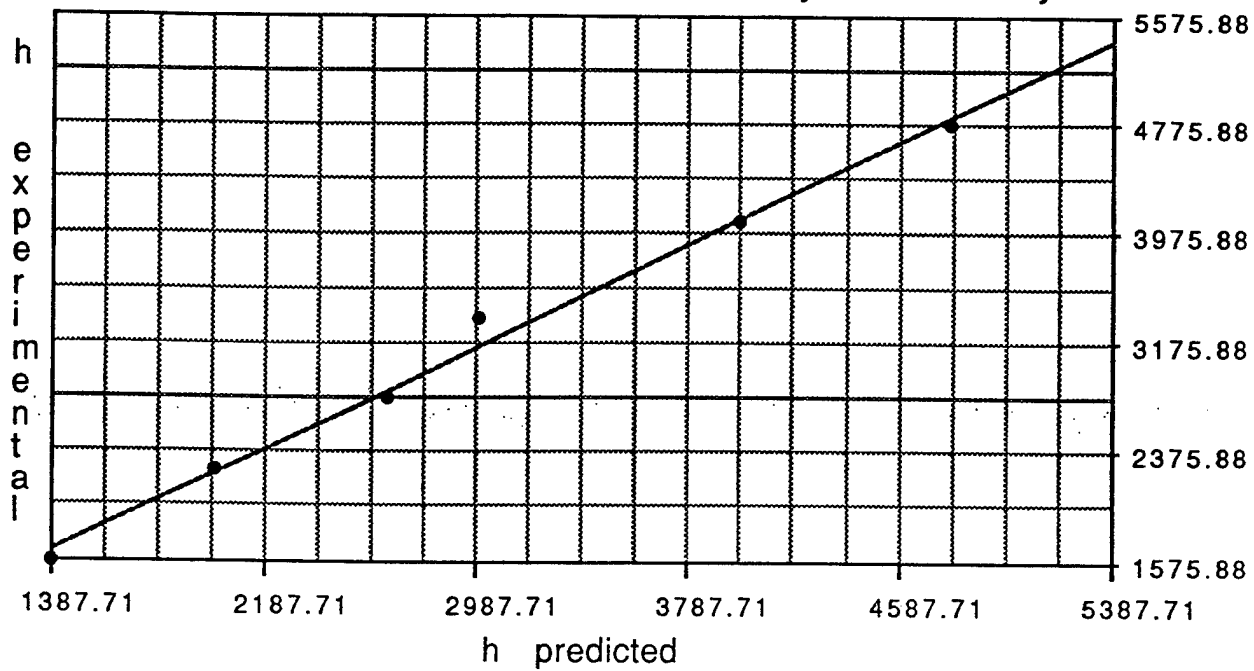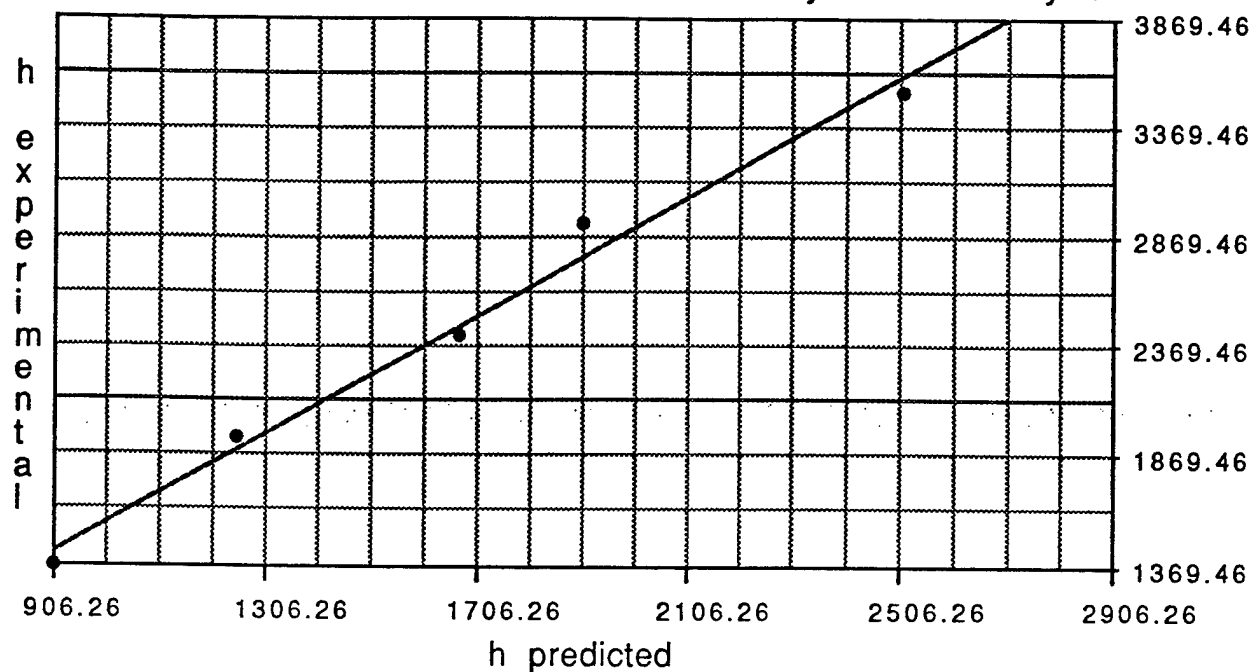Correlation Coefficient = .996903
Std. Error about Regression Line = 151.806
t Statistic (Hypothesis: Slope=0) = 28.3435

X-axis file: DW_98.44_hpred_NC
Y-axis file: DW_98.44_hexptl

Exptl Data for Water at 66.65 kPa vs Data by Present Analysis
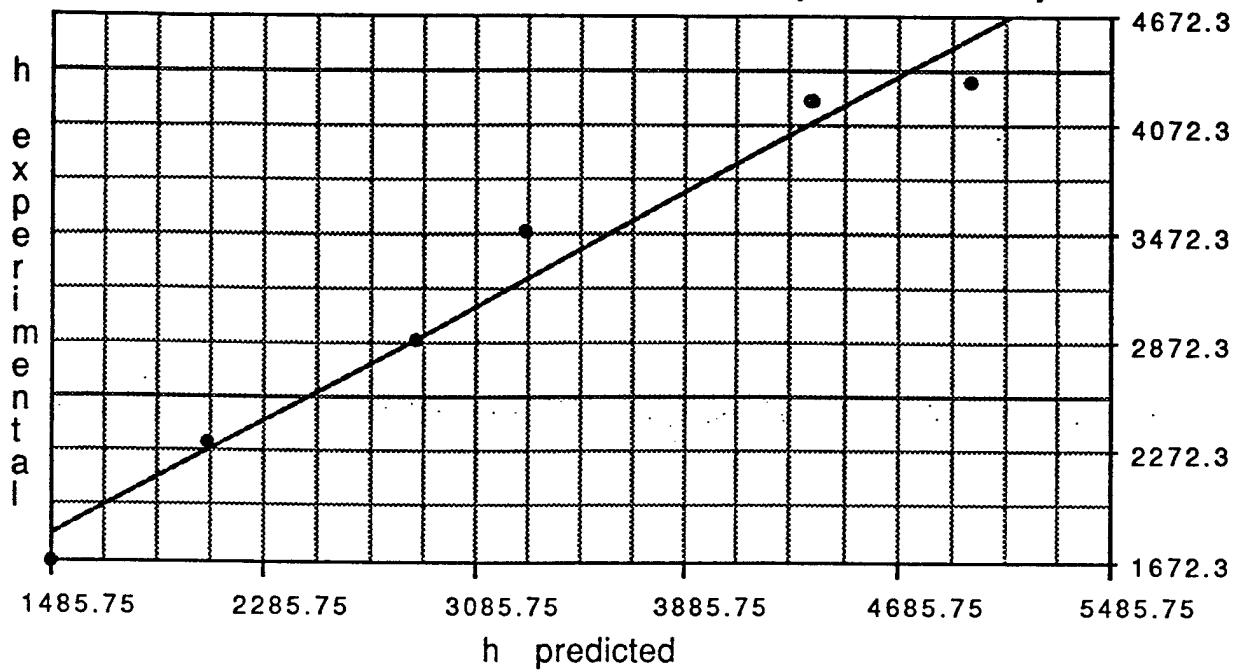
Report Created: 03-22-1995   2:57:04 PM

Linear Best Fit Curve
Pts Plotted = 6   Offscale Pts = 0

Regression Equation:
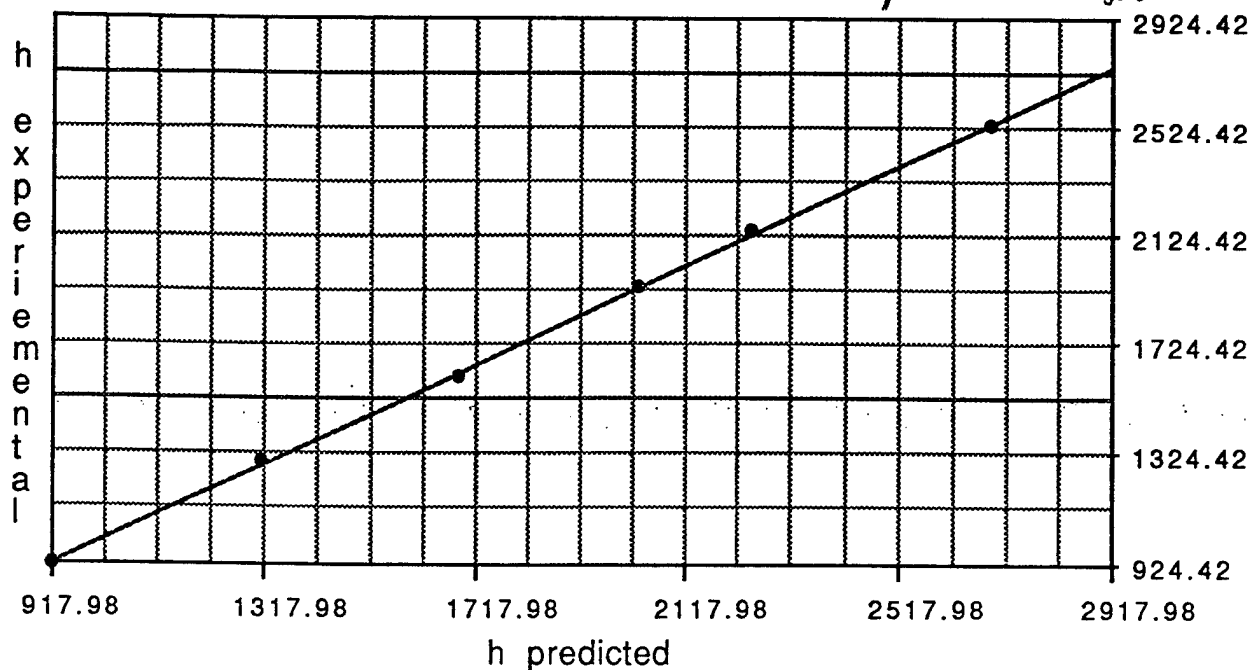Y = .78328 X + (665.974)

Correlation Coefficient = .985499
Std. Error about Regression Line = 200.036
t Statistic (Hypothesis: Slope=0) = 11.6159

X-axis file: DW_66.65_hpred_NC
Y-axis file: DW_66.65_hexptl

Exptl Data for Water at 47.32 kPa vs Data by Present Analysis

Report Created: 03-22-1995   3:11:52 PM

Linear Best Fit Curve
Pts Plotted = 6   Offscale Pts = 0

Regression Equation:
Y = .936071 X + (351.551)

Correlation Coefficient = .99613
Std. Error about Regression Line = 115.655
t Statistic (Hypothesis: Slope=0) = 22.6673

X-axis file: DW_47.32_hpred_NC
Y-axis file: DW_47.32_hexptl

Exptl Data for Water at 11.33 kPa vs Data by Present Analysis

Report Created: 03-22-1995   3:27:57 PM

Linear Best Fit Curve
Pts Plotted = 5   Offscale Pts = 0

Regression Equation:
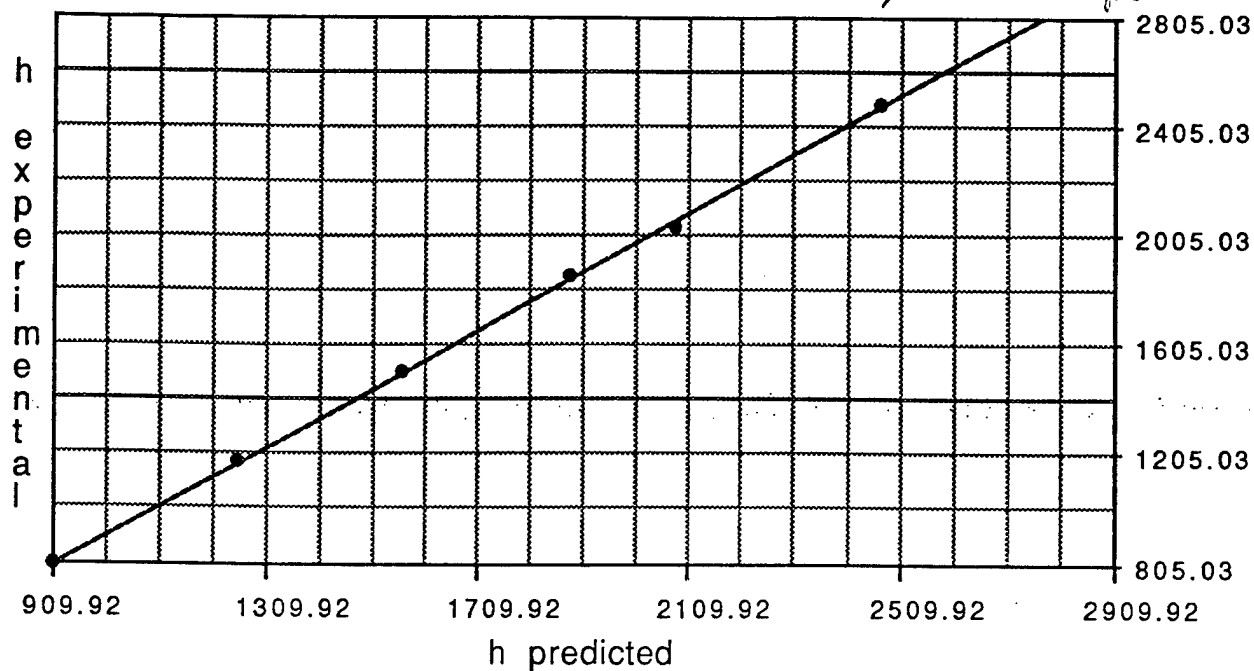$Y = 1.35074 X + (210.327)$

Correlation Coefficient = .993605
Std. Error about Regression Line = 109.362
t Statistic (Hypothesis: Slope=0) = 15.2412

X-axis file: DW_11.33_hpred_NC
Y-axis file: DW_11.33_hexptl

Exptl Data for Methanol at 98.64 kPa vs Data by Present Analysis

h predicted

Report Created: 03-22-1995   3:35:17 PM

Linear Best Fit Curve
Pts Plotted = 6   Offscale Pts = 0

Regression Equation:
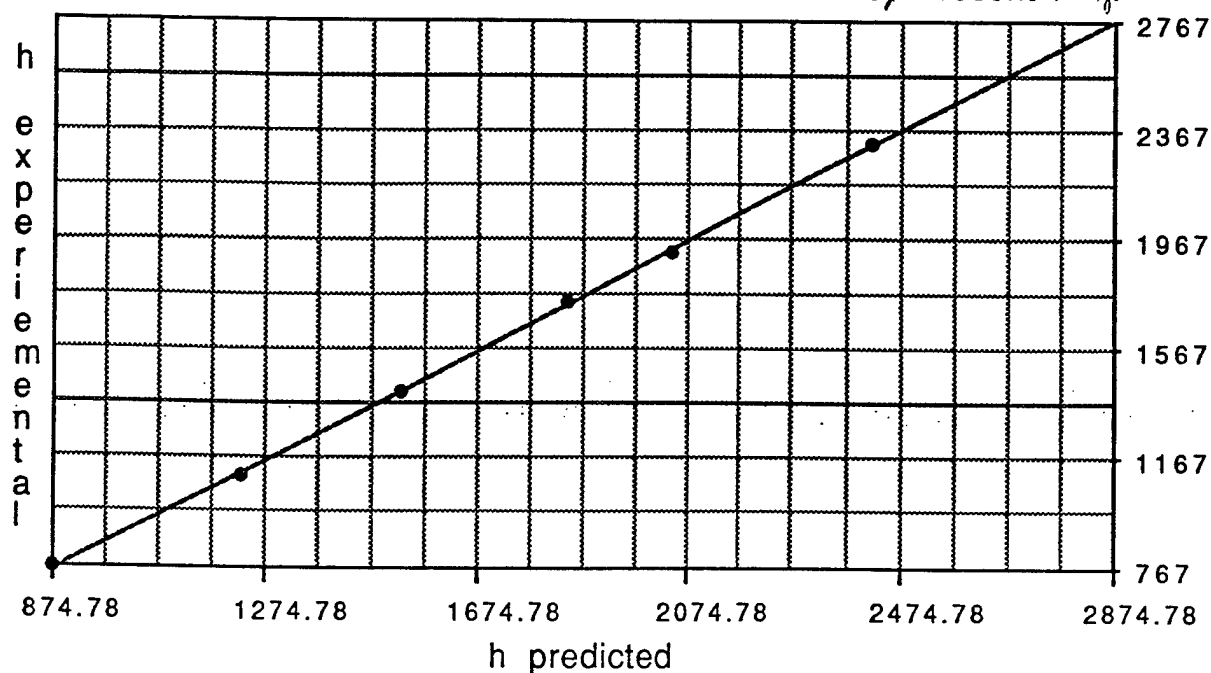Y = .907214 X + (93.6134)

Correlation Coefficient = .999896
Std. Error about Regression Line = 9.41357
t Statistic (Hypothesis: Slope=0) = 138.589

X-axis file: ML_98.64_hpred_NC
Y-axis file: ML_98.64_hexptl

Exptl Data for Methanol at 79.98 kPa vs Data by Present Analysis

Report Created: 03-22-1995   3:44:38 PM

Linear Best Fit Curve
Pts Plotted = 6   Offscale Pts = 0

Regression Equation:
Y = 1.07008 X + (-169.078)

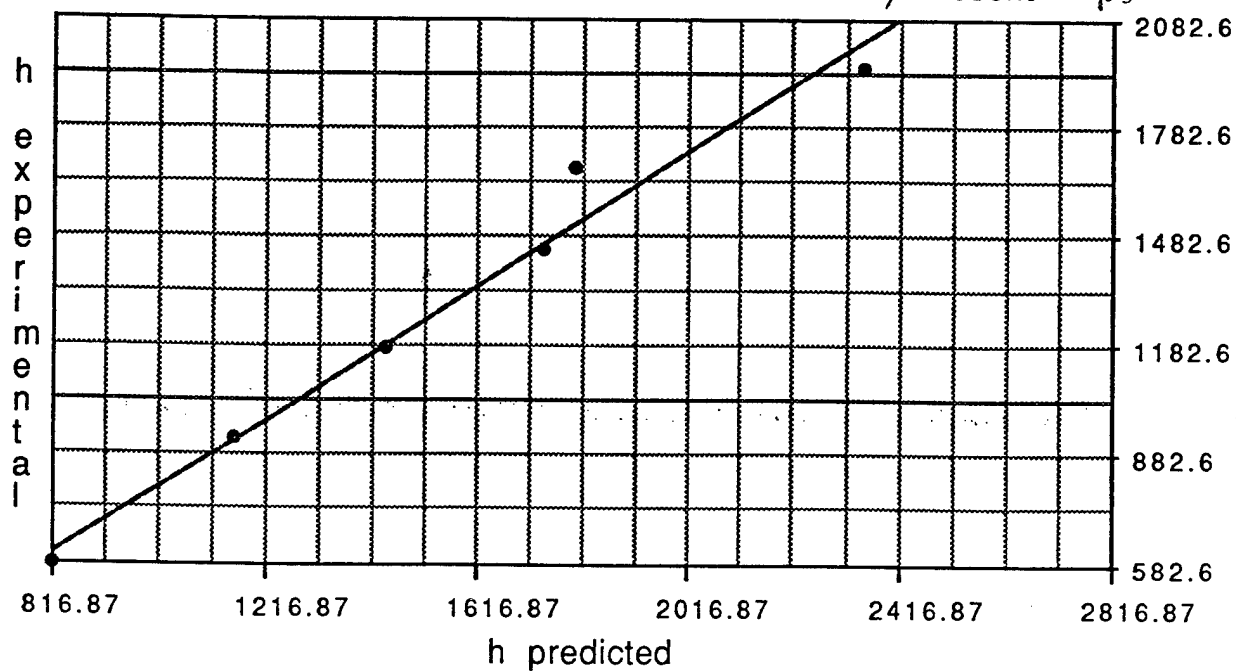Correlation Coefficient = .999788
Std. Error about Regression Line = 14.0147
t Statistic (Hypothesis: Slope=0) = 97.1241

X-axis file: ML_79.98_hpred_NC
Y-axis file: ML_79.98_hexptl

Exptl Data for Methanol at 66.65 kPa vs Data by Present Analysis

Report Created: 03-22-1995   3:52:43 PM

Linear Best Fit Curve
Pts Plotted = 6   Offscale Pts = 0

Regression Equation:
$Y = 1.0082 X + (-130.084)$

Correlation Coefficient = .999784
Std. Error about Regression Line = 13.1456
t Statistic (Hypothesis: Slope=0) = 96.1457

X-axis file: ML_66.65_hpred_NC
Y-axis file: ML_66.65_hexptl

Exptl Data for Methanol at 41.32 kPa vs Data by Present Analysis

Report Created: 03-22-1995   4:05:23 PM

Linear Best Fit Curve

Pts Plotted = 6   Offscale Pts = 0

Regression Equation:

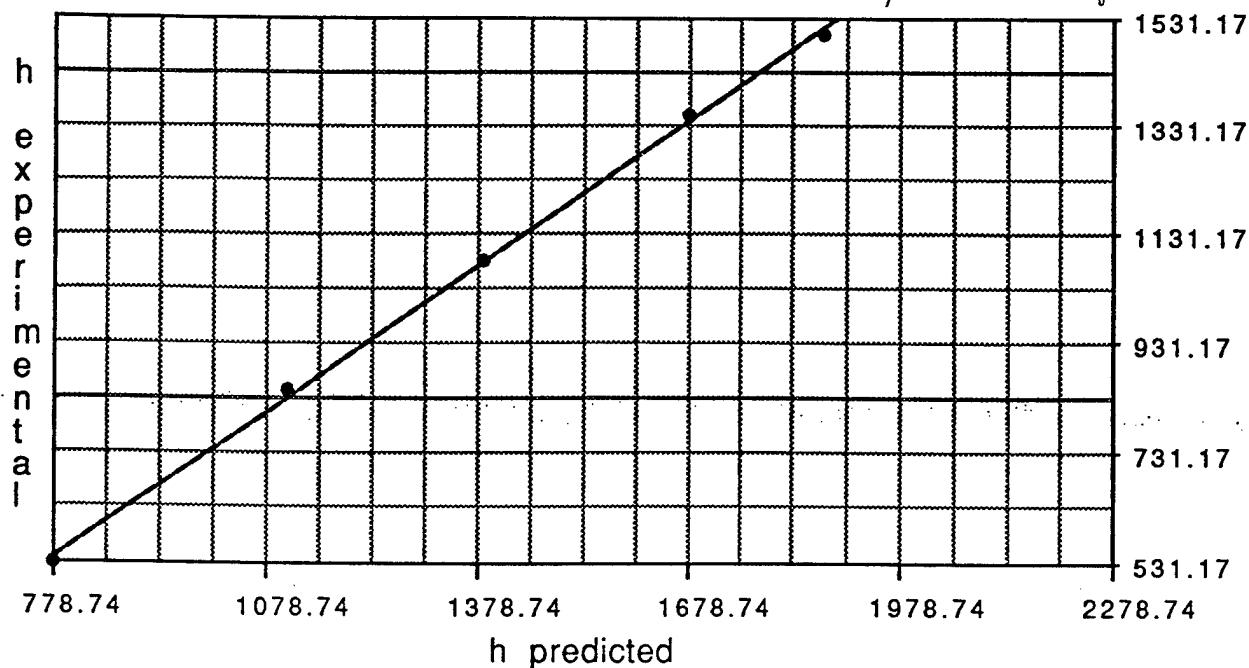$Y = .917809 X + (-134.101)$

Correlation Coefficient = .988162
Std. Error about Regression Line = 85.4739
t Statistic (Hypothesis: Slope=0) = 12.8824

X-axis file: ML_41.32_hpred_NC
Y-axis file: ML_41.32_hexptl

Exptl Data for Methanol at 27.99 kPa vs Data by Present Analysis

h experimental (y-axis): 531.17, 731.17, 931.17, 1131.17, 1331.17, 1531.17

h predicted (x-axis): 778.74, 1078.74, 1378.74, 1678.74, 1978.74, 2278.74

Report Created: 03-22-1995   4:11:12 PM

Linear Best Fit Curve
Pts Plotted = 5   Offscale Pts = 0

Regression Equation:
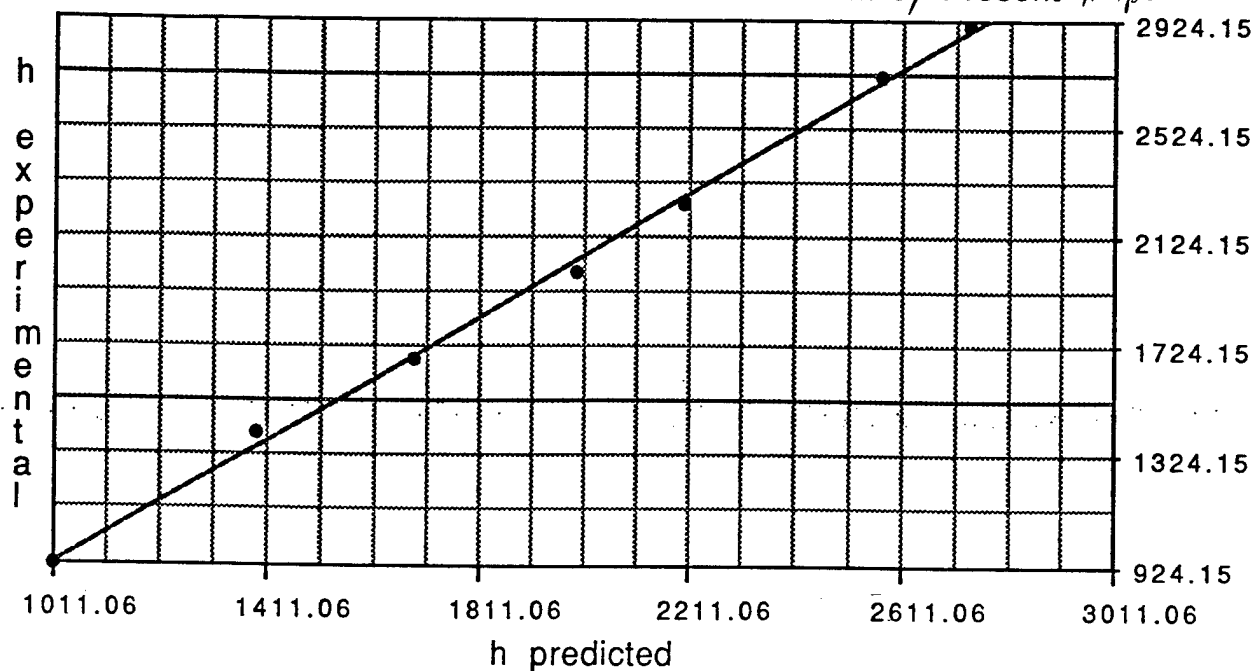Y =   .889673 X + (-151.658)

Correlation Coefficient = .999616
Std. Error about Regression Line = 12.4373
t Statistic (Hypothesis: Slope=0) = 62.5031

X-axis file: ML_27.99_hpred_NC
Y-axis file: ML_27.99_hexptl

Exptl Data for Isopropanol at 97.98 kPa vs Data by Present Analysis

Report Created: 03-22-1995   4:17:34 PM

Linear Best Fit Curve
Pts Plotted = 7   Offscale Pts = 0

Regression Equation:
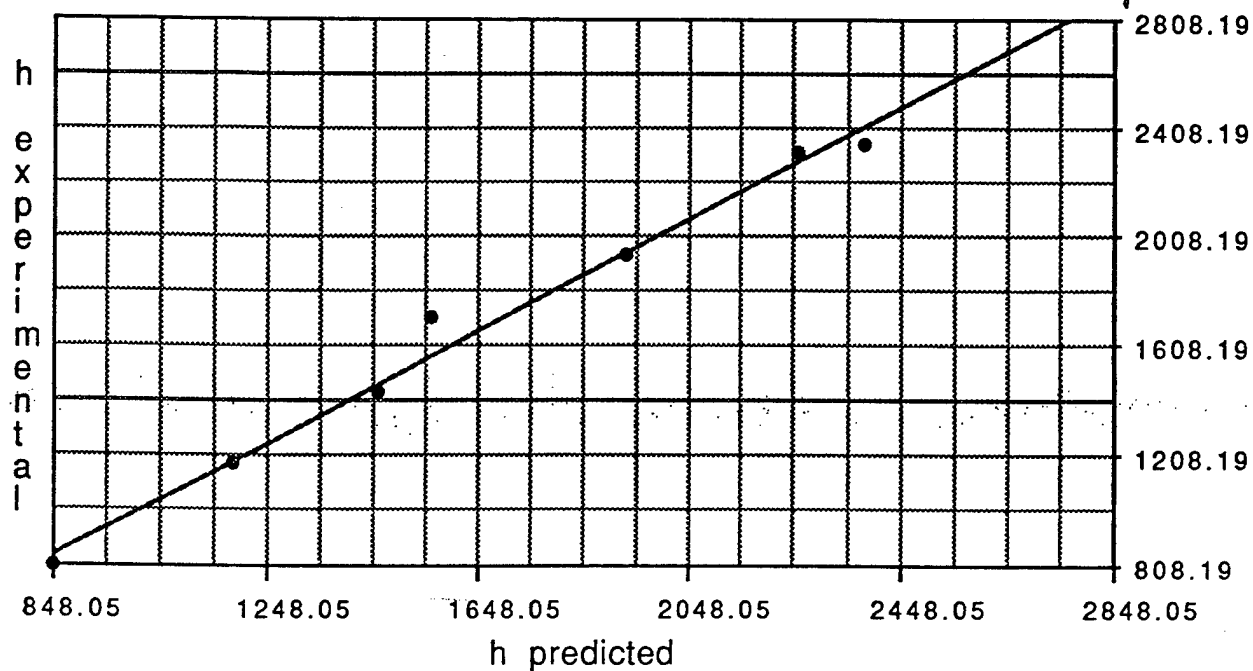$Y = 1.13657 X + (-225.507)$

Correlation Coefficient = .998991
Std. Error about Regression Line = 34.8752
t Statistic (Hypothesis: Slope=0) = 49.7367

X-axis file: IL_97.98_hpred_NC
Y-axis file: IL_97.98_hexptl

Exptl Data for Isopropanol at 67.28 kPa vs Data by Present Analysis

(y-axis label: h experimental; scale: 808.19, 1208.19, 1608.19, 2008.19, 2408.19, 2808.19)

(x-axis label: h predicted; scale: 848.05, 1248.05, 1648.05, 2048.05, 2448.05, 2848.05)

Report Created: 03-22-1995   4:36:51 PM

Linear Best Fit Curve
Pts Plotted = 7   Offscale Pts = 0

Regression Equation:
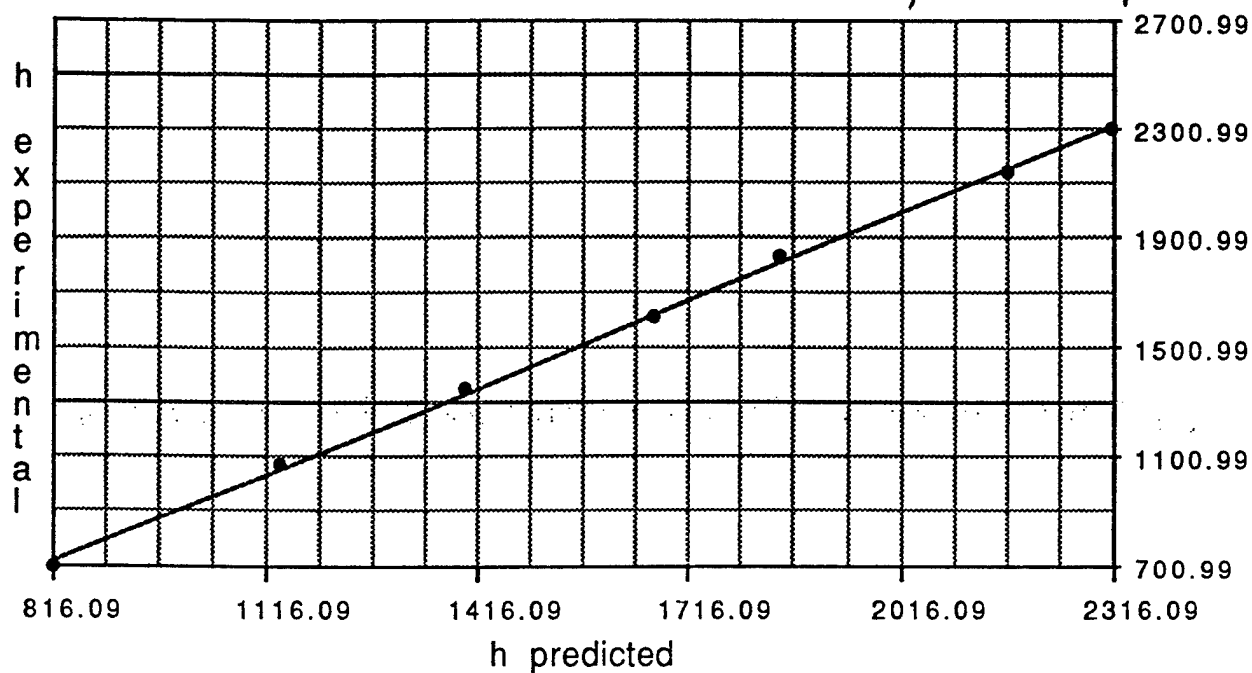Y = 1.02147 X + (-16.0477)

Correlation Coefficient = .993438
Std. Error about Regression Line = 72.1817
t Statistic (Hypothesis: Slope=0) = 19.4231

X-axis file: IL_67.28_hpred
Y-axis file: IL_67.28_hexptl

Exptl Data for Isopropanol at 54.65 kPa vs Data by Present Analysis

Report Created: 03-22-1995   4:42:12 PM

Linear Best Fit Curve

Pts Plotted = 7   Offscale Pts = 0

Regression Equation:
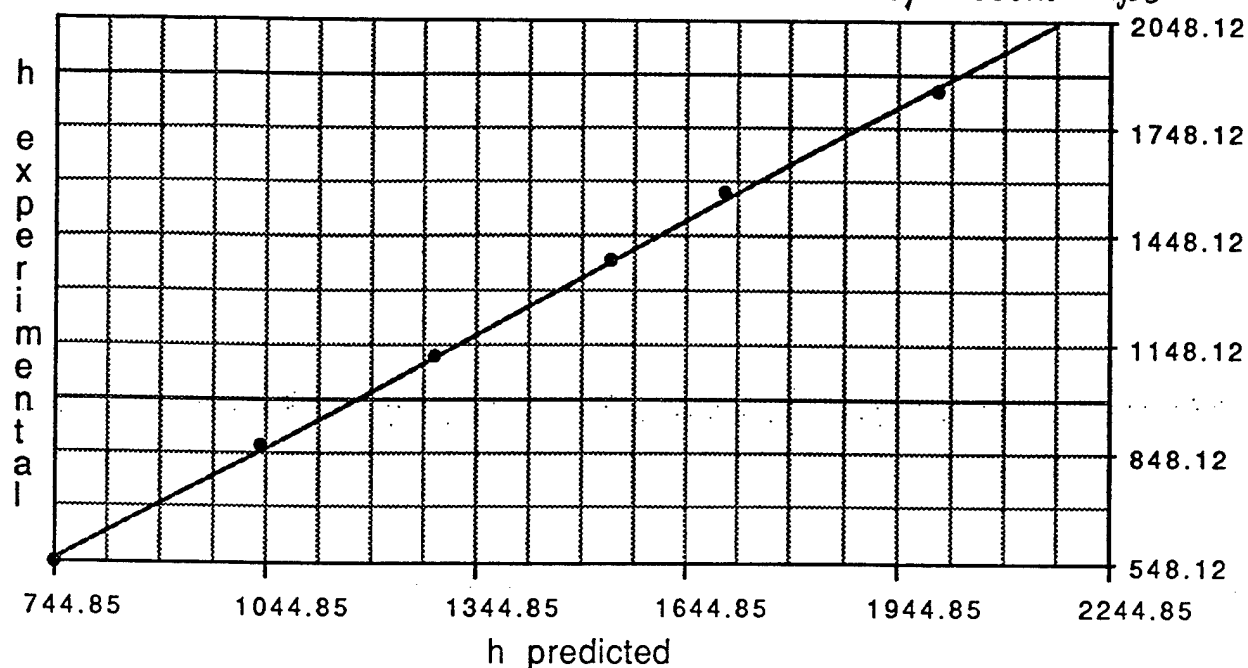Y =   1.05855 X + (-143.265)

Correlation Coefficient = .999589
Std. Error about Regression Line = 18.0339
t Statistic (Hypothesis: Slope=0) = 77.962

X-axis file: IL_54.65_hpred_NC
Y-axis file: IL_54.65_hexptl

Exptl Data for Isopropanol at 29.33 kPa vs Data by Present Analysis

Report Created: 03-22-1995   4:56:00 PM

Linear Best Fit Curve
Pts Plotted = 6   Offscale Pts = 0

Regression Equation:
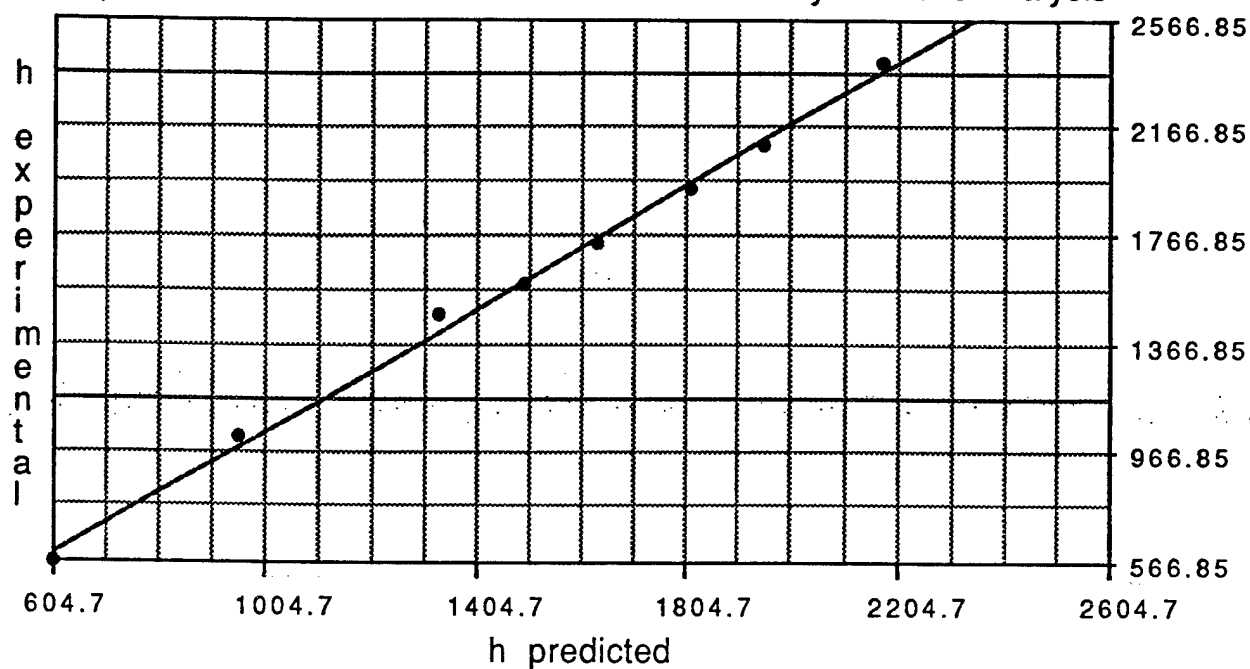$Y = 1.04512 X + (-223.397)$

Correlation Coefficient = .999795
Std. Error about Regression Line = 10.7979
t Statistic (Hypothesis: Slope=0) = 98.7593

X-axis file: IL_29.33_hpred_NC
Y-axis file: IL_29.33_hexptl

Exptl Data for Ethanol at 98.18 kPa vs Data by Present Analysis

Report Created: 03-22-1995 5:00:58 PM

Linear Best Fit Curve
Pts Plotted = 8   Offscale Pts = 0

Regression Equation:
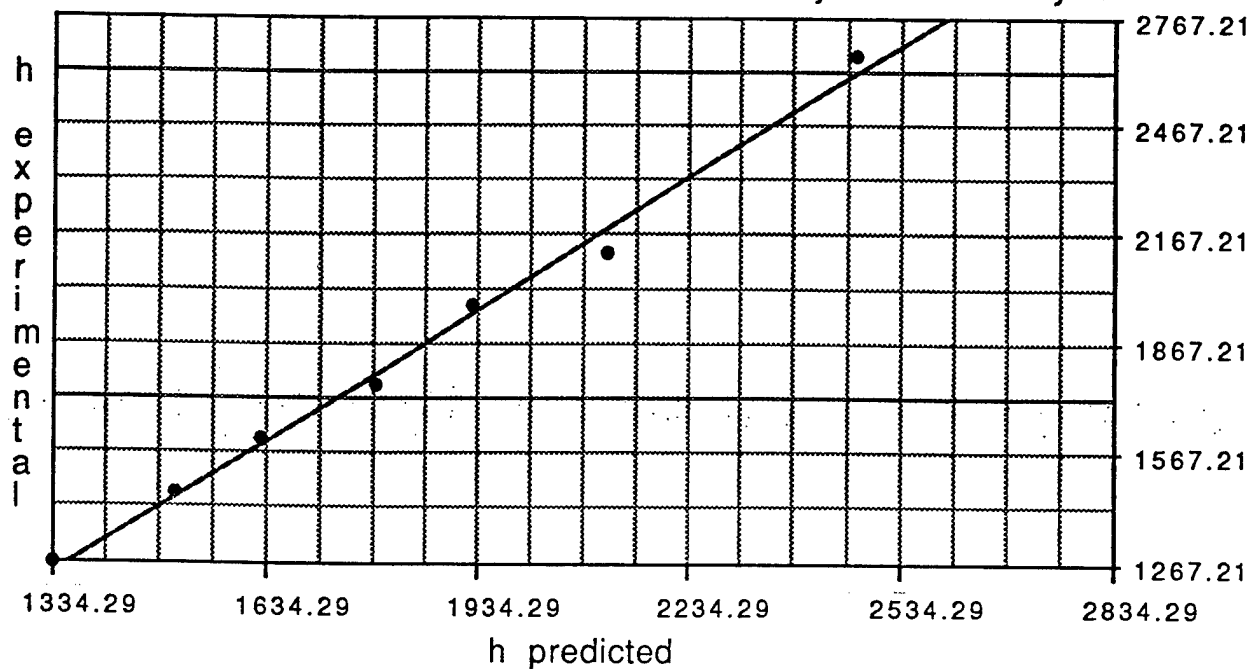Y = 1.12812 X + (-83.1872)

Correlation Coefficient = .998043
Std. Error about Regression Line = 39.8133
t Statistic (Hypothesis: Slope=0) = 39.0937

X-axis file: EL_98.18_hpred_NC
Y-axis file: EL_98.18_hexptl

Exptl Data for Ethanol at 84.85 kPa vs Data by Present Analysis

Report Created: 03-22-1995   5:07:17 PM

Linear Best Fit Curve
Pts Plotted = 7   Offscale Pts = 0

Regression Equation:
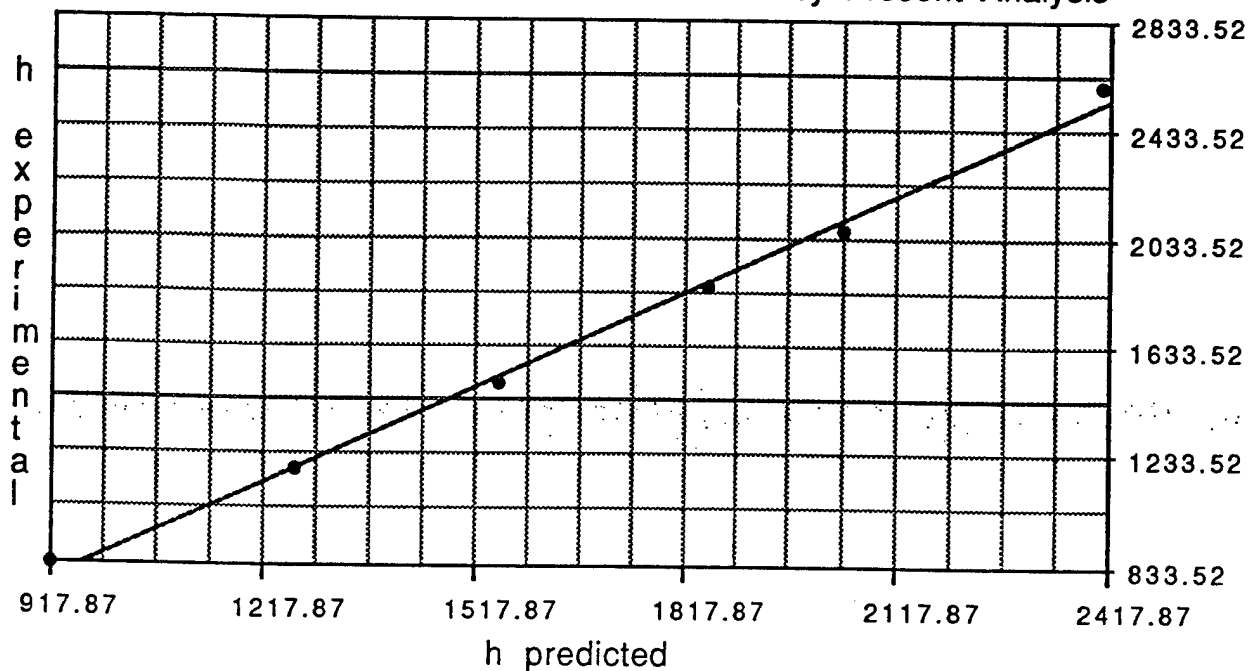Y = 1.20399 X + (-363.563)

Correlation Coefficient = .996072
Std. Error about Regression Line = 45.3411
t Statistic (Hypothesis: Slope=0) = 25.1532

X-axis file: EL_84.85_hpred_NC
Y-axis file: EL_84.85_hexptl

Exptl Data for Ethanol at 71.32 kPa vs Data by Present Analysis

Report Created: 03-22-1995   5:12:19 PM

Linear Best Fit Curve
Pts Plotted = 6   Offscale Pts = 0

Regression Equation:
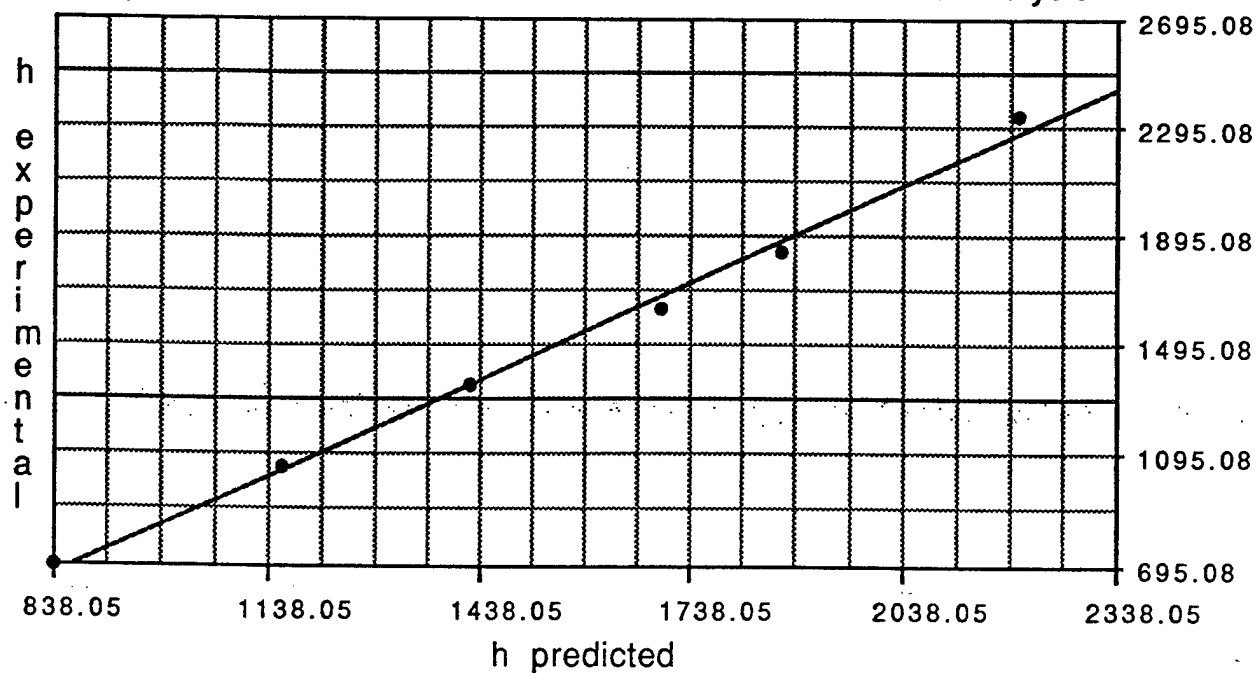Y = 1.17681 X + (-298.705)

Correlation Coefficient = .997439
Std. Error about Regression Line = 50.9419
t Statistic (Hypothesis: Slope=0) = 27.894

X-axis file: EL_71.32_hpred_NC
Y-axis file: EL_71.32_hexptl

Exptl Data for Ethanol at 44.65 kPa vs Data Present Analysis

Report Created: 03-22-1995   5:18:08 PM

Linear Best Fit Curve
Pts Plotted = 6   Offscale Pts = 0

Regression Equation:
$Y = 1.17696 X + (-320.825)$
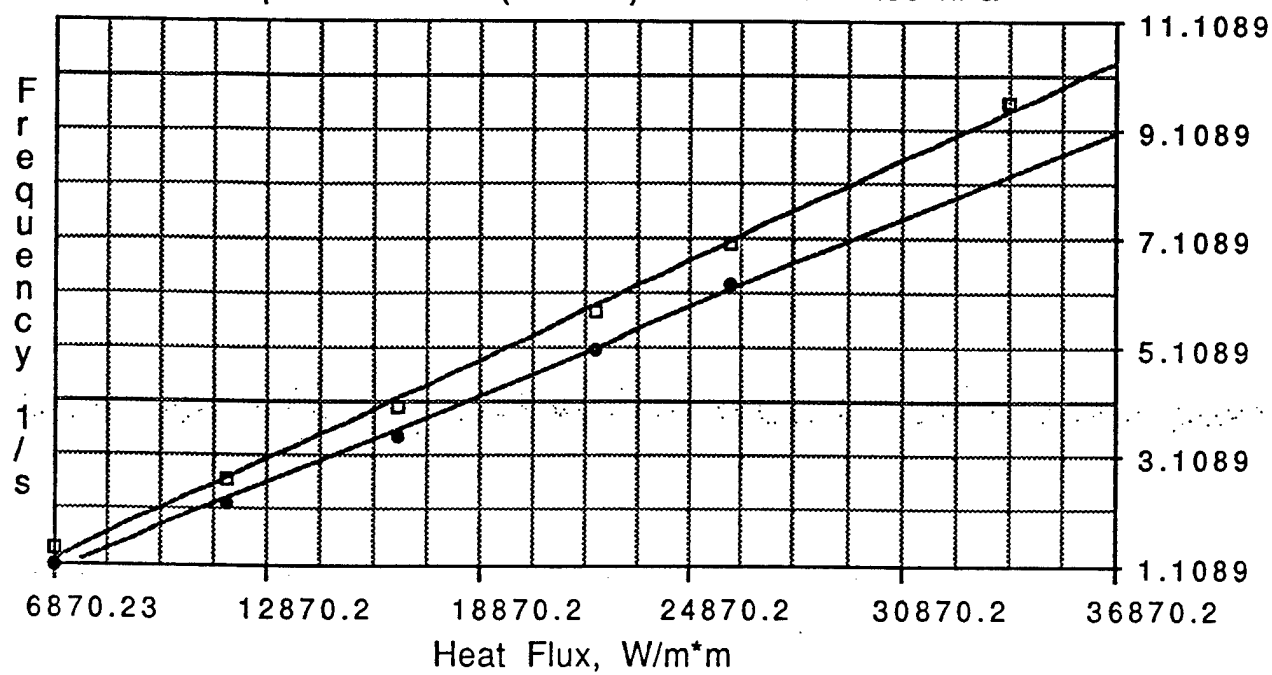
Correlation Coefficient = .997005
Std. Error about Regression Line = 50.4182
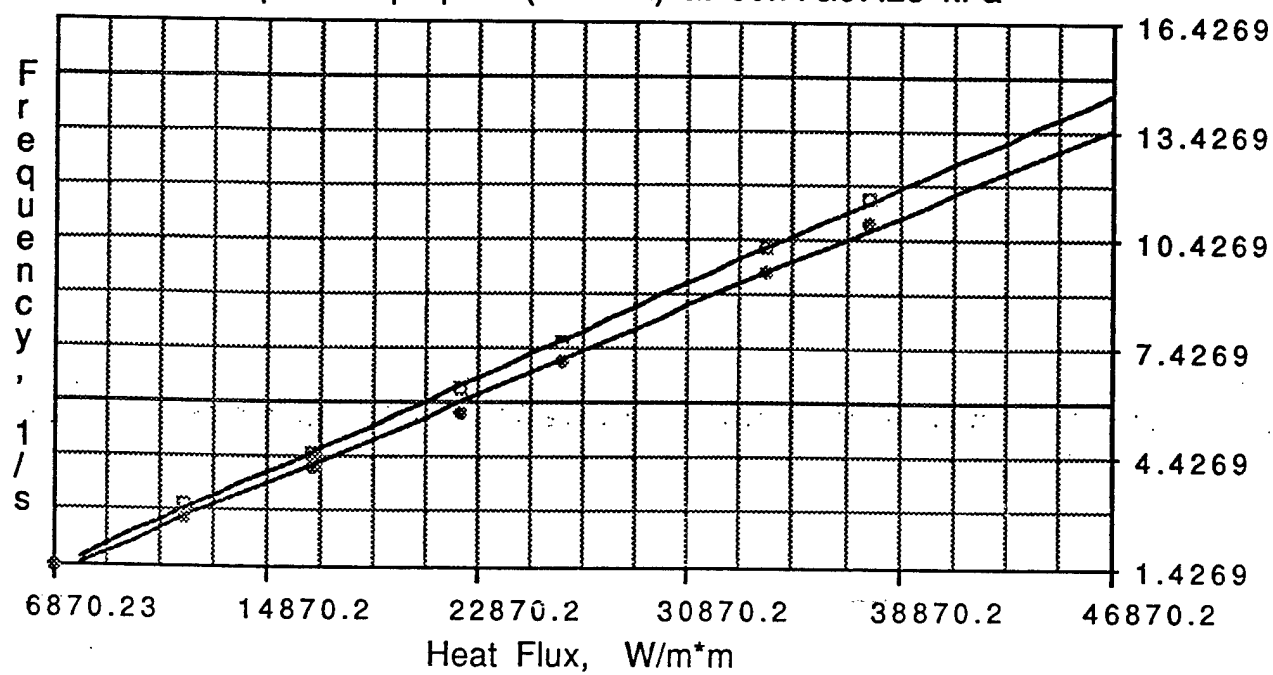t Statistic (Hypothesis: Slope=0) = 25.785

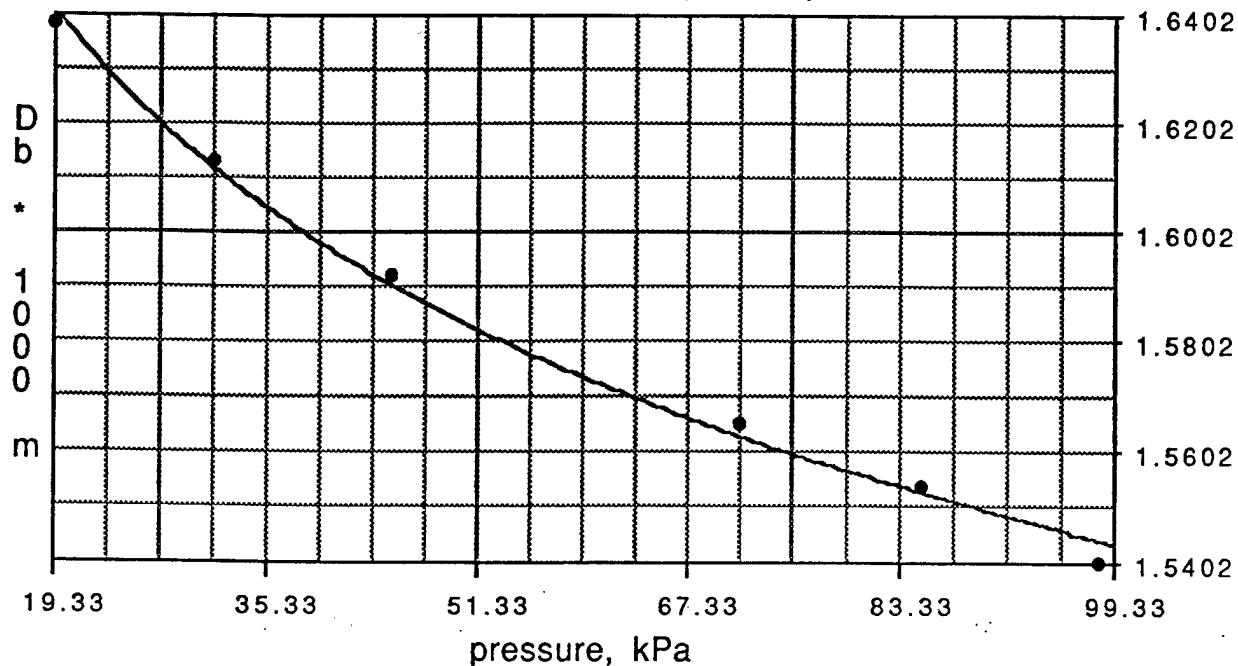X-axis file: EL_44.65_hpred_NC
Y-axis file: EL_44.65_hexptl

f vs q for Methanol (Sharma) at 98.64 & 27.99 kPa

f vs q for Isopropanol(Sharma) at 80.77&67.28 kPa

Db vs P for Ethanol (Sharma)

pressure, kPa

Report Created: 03-23-1995   5:07:46 PM

Power Curve Fit
Pts Plotted = 6   Offscale Pts = 0

Regression Equation:
$Y = 1.8345 X^{-3.75544E-02}$

Correlation Coefficient = -.997546

X-axis file: EL_p_X_PRS
Y-axis file: EL_Db_Y_PRS